Internal Circulation In Tidal Channels And Straits
And
Internal Circulation In Tidal Channels And Straits: A Comparison Of Observed And Numerical Turbulence Estimates (AASERT)

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LONG-TERM GOAL

The principal long-term objectives of this project and its associated AASERT are to provide:

- a 3-D conceptual understanding of circulation and scalar transport in the numerous estuaries and straits worldwide with both strong tides and buoyancy forcing,
- improved analysis methods based on continuous wavelet transforms for defining the non-stationary and non-linear processes that drive circulation in these environments, and
- in concert with related projects, an improved understanding of vertical turbulent mixing processes in stratified estuarine flows.

OBJECTIVES

Present work focuses on the 3-D distribution of the along-channel circulation, hydraulic control and mixing at the estuary entrance, and near-bed and interfacial mixing processes in stratified environments. Specific objectives include:

- test a 3-D mixed analytical/numerical circulation model for sub-areas of the Columbia River estuary, to calculate tidal and residual flow during periods for which data are available;
- examine hydraulic control effects near the mouth of the Columbia River using a three-layer model that includes mixing between layers and bed dissipation;
- analyze near-bed and interfacial turbulent momentum, salt and sediment flux data to better understand vertical fluxes of momentum, salt and sediment in stratified environments;
- develop and disseminate to the oceanographic community wavelet transform tidal analysis and turbulence estimation tools; and
- use wavelet and other tools to analyze key data sets.

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APPROACH

This project takes a unified approach to analyzing the effects of buoyancy on estuarine and shelf tides and scalar transport, as funded by the Coastal Dynamics Program of ONR and the National Science Foundation (NSF) Land-Margin Ecosystem Research (LMER) Program. In all environments of interest, a time-varying density field leads to markedly unsteady tidal flow, which in turn feeds back onto the density field through tidal straining and variable mixing. Scalar transports then depend on the detailed correlations of time-dependent velocity and scalar fields and on vertical turbulent mixing. On a functional level, these efforts have been augmented over the last two years through data collected by the ONR-funded Oceanographic and Environmental Characterization of Coastal Regions (OECCR). The CORIE nowcast-forecast system developed through OECCR provides a large data set that requires interpretation. The understanding that is being developed through the tidal channels project can be transferred to other environments world-wide, just as can the OECCR modeling and forecast methods.

WORK COMPLETED

1. Acoustic Doppler profiler (ADP) backscatter has been calibrated and used to calculate suspended particulate material (SPM) concentration and horizontal transport over time scales of months, providing an understanding of the seasonal variations in SPM transport associated with changes in flow and tidal range (Jay et al., 1999). We have also developed an inverse analysis that builds on Lynch and Agrawal (1991) to separate the different settling classes detected in acoustic backscatter profiles.

2. Estimates of key turbulence parameters for near-bed and interfacial locations have been made at all stages of the tide at mid-estuary locations. Time series of TKE, stress components, dissipation and buoyancy flux have been calculated (Jay and Kay submitted 1999a,b). Acoustic backscatter from a Sontek field acoustic Doppler velocimeter (ADV) has been calibrated and used to calculate vertical sediment fluxes and interpret estuarine suspended sediment processes.

3. A semi-analytical model of estuarine circulation has been completed, tested against selected data sets and used to investigate the effects of typical topographies on mean and tidal circulation (Musiak and Jay, in preparation).

4. A three-layer, laterally averaged model with interfacial mixing and bedstress has been constructed and tested through joint ONR and LMER support. It has been used to examine hydraulic control, mixing and circulation at the estuary entrance (Cudaback and Jay, submitted 1999a,b). The model reproduces typical flood and ebb structures seen in shallow entrances with internal hydraulic controls. We are now attempting to draw more general conclusions concerning the importance of vertical mixing in estuary mouths.

5. Wavelet tidal analysis methods have also been extended to data with gaps, a non-trivial issue with linear filters. Methods have been documented (Flinchem and Jay, accepted 1999) an comparisons of traditional harmonic analysis and wavelet methods carried out (Jay and Flinchem, 1999).

6. In conjunction with the LMER program, a comparison of the Columbia and Fraser river salt wedge salinity intrusion and ETM dynamics has been carried out (the 1999 Fraser-Columbia Comparison cruise), as well as examimation of the Fraser River inner plume dynamics focusing on plume lift-off (Figure 1.)

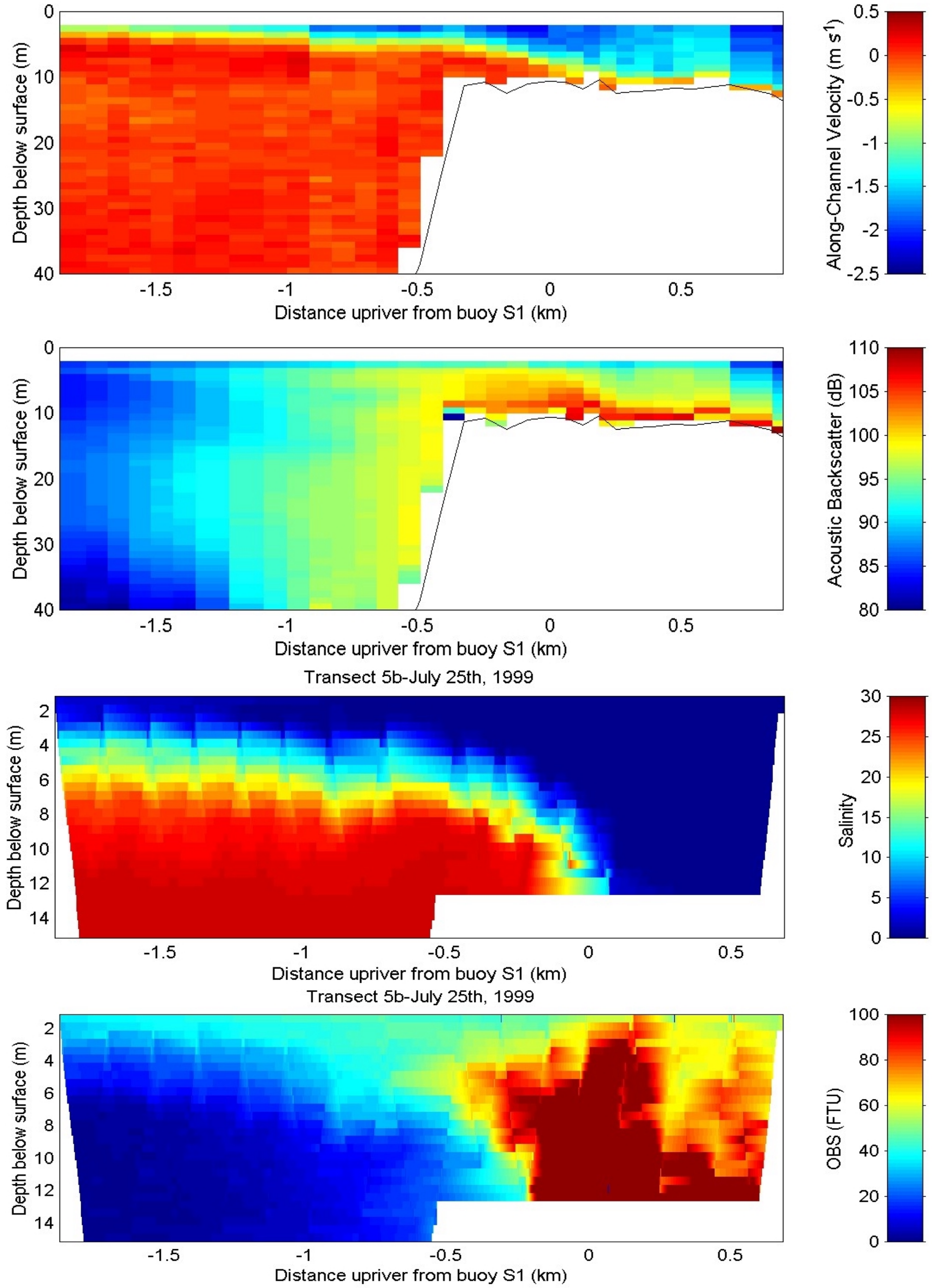

Fig. 1: A 25 July 1999 ebb transect across the Fraer River mouth showing plume lift-off and an estuarine turbidity maximum (ETM). Alongchannel velocity (m^{s-1}) and ABS (db) from a 300 kHz ADCP are shown at top, salinity and OBS (FTU) below; note that the upper and lower panels have different vertical scales. The ETM is centered at the head of salinity intrusion, and plume SPM concentrations (inferred qualitatively from ABS or OBS) drop off rapidly in the seaward direction. The OBS scale has also been truncated at 100 FTU to emphasize lower plume concentrations; ETM concentrations were as high as 800 FTU in the ETM.

RESULTS

Stratified Flow over Typical Estuarine Topography (Low Internal Froude Numbers): Traditional estuarine circulation theory has not led to a clear understanding of stratified estuarine flow over topography, because the only tools available were very simple theories for uniform or geometric changes in width and depth (on the one hand) and complex 3-D numerical models (on the other). We have developed and tested an intermediate, semi-analytic profile model valid for shallow estuaries and low internal Froude numbers, averaged over a tidal cycle (Musiak, 1998; Musiak and Jay, in preparation 1999).

Hydraulic Control at an Estuary Mouth (High Internal Froude Numbers): Two-layer hydraulic control theory exhibits many features of estuarine circulation, but cannot reproduce the pronounced flood interfacial jet and ebb expansion of the interfacial layer to encompass most or all of the flow. Also typical of estuarine entrances is the existence of critical or super-critical internal Froude numbers for much of the tidal cycle. This type of flow is best handled using a three layer model. We have developed a model that generalizes a prior two-layer model of Helfrich (1995) by including bed friction, an explicit interface layer and turbulent entrainment between layers. The model nicely re-produces the interfacial jet on flood and to a lesser extent the breakdown in layers on ebb (Cudaback (1998); Cudaback and Jay, submitted 1999a,b).

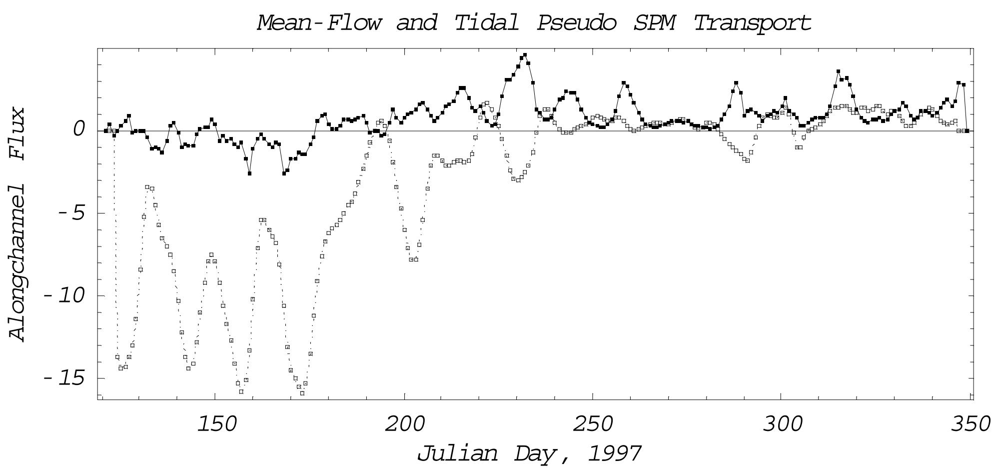

Figure 2: Non-tidal near-bed SPM transport from CWT analysis: sum of major tidal species (®) and mean-flow transports (©). Net transport is outward during the spring freshet, particularly on spring tides, and landward otherwise. Note the opposition of wave and mean transports during much of the deployment. Data between ~d 240-290 are invalid due to biofouling of the sensor.

SPM Transport Processes in Estuarine Turbidity Maxima (ETM): One of the advantages of ADP velocity measurements is that simultaneous determinations of SPM concentration and SPM transport are possible, once the ADP backscatter has been calibrated (in our case by LMER). CORIE ADP time series data provide an ability to examine the response of ETM transport processes to external changes in river flow, SPM supply and tidal range (e.g., Figure 2). This is quite important both for understanding estuarine particle trapping and for the insight it gives to estuarine ecosystem processes based on reprocessing of particulate organics. This work has generated the hypothesis that estuaries amplify climate signals through their SPM budget; this is now being tested under NSF funding.

Analyses of Turbulent Processes: These are vital to Tidal Channels modeling, for development of a qualitative understanding of estuarine scalar transport, and for improvement of numerical turbulence

algorithms. Acoustic Doppler velocimeter (ADV) technology provides impressive capabilities and can be used in a variety of ways, provided one is aware of its strengths and weaknesses (Voulgaris and Trowbridge, 1997). We have calculated major terms in the turbulent kinetic energy (TKE) budget and their variations with time, and used a novel approach to modeling the along-channel momentum and density balances from data to estimate the partition between internal and bed energy losses on a neap tide. Internal losses were found to be dominant under the conditions examined.

IMPACTS/APPLICATIONS

1. The CWT analysis methods devised in this project should be widely applicable to analyses of non-stationary tidal phenomena and also to the problem of optimal extraction of frequencies from a short record. Together, these circumstances constitute a large percentage of all applications of tidal analysis. CWTs can also provide a consistent analysis of tidal and subtidal variance very difficult to carry out with harmonic analysis.

2. Understanding optical and acoustic properties in the littoral requires a unified approach to physical and ecosystem dynamics, because littoral ecosystems are so strongly forced by advection and mixing. In this regard, the collaborative approach of the Tidal Channels project with other research funded by ONR and the National Science Foundation can serve as a good model.

3. The three-layer internal hydraulics model and the more general semi-analytical 3-D modeling approach being developed under this project should be widely applicable to other estuaries and should materially improve our understanding of estuarine circulation.

4. The analyses of vertical turbulent mixing processes should provide an improvement in qualitative understanding of turbulent mixing processes, as well as suggesting methods by which numerical model procedures might be improved.

5. The calibration of ADV and ADP backscatter should provide a valuable method for estimating horizontal and vertical SPM fluxes. This approach is especially valuable when combined with CWT analysis methods, so that the dominant transport processes may be determined. The inverse analysis of acoustic backscatter profiles should provide a basis for improving our understanding of the SPM dynamics of tidal straits and channels.

TRANSITIONS

Two CWT tidal analysis programs with sample data sets illustrating their use have been placed on the PI's web page (see CWT software library sub-heading under http://www.ccalmr.ogi.edu/ ~djay). Dr. R. Signell of the US Geological Survey has also set up a link to these programs on his Sea-Mat web site (http://crusty.er.usgs.gov/sea-mat).

RELATED PROJECTS

Work for the Tidal Channels project has been coordinated with the National Science Foundation Columbia River Land-Margin Ecosystem Research (LMER) Program and with the Oceanographic and Environmental Characterization of Coastal Regions (OECCR) funded by ONR. SPM transport ideas developed here and through LMER have led to the hypothesis that estuaries amplify climate signals

through their sediment budget. This idea is being pursued through a funded NSF Small Grant for Exploratory Research.

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